Resistance Scaling and Predictions of SLICE Hulls from Model Tests

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Objectives

- Extrapolate ship resistances from model test data
- modify present day accepted scaling techniques, which were derived for monohulls, to fit the SLICE design

Resistance

- How much will the ship have ?
- Will the ship achieve the desired speed?
- What are the sources ?

Modeling

- Build a model and test it in a tank
- Determine required force to tow the model at incremental speeds
- At a constant velocity, this force equals the resistance.
- Extrapolate ship resistance from model data

Model Test Data

- Dimensions from Lockheed ship drawings
- From Lockheed tests:
  - model velocities
  - total drag = force required to tow at constant speeds
  - fluid parameters

Froude Hypothesis: a modern interpretation

$$C_T(Rn, Fn) = C_F(Rn) + C_R(Rn, Fn)$$

$$C_T(Rn, Fn) = C_F(Rn) + C_{WM}(Fn) + C_{FORM}$$

Ship Resistance Predictions

- Two accepted approaches used to extrapolate ship resistances from model data
  - ITTC
  - Hughes
- Both employ Rn and Fn scaling, but in different ways

ITTC

- Uses Froude hypothesis
- Coefficients
  - Frictional — Rn scaled
  - Wave Making — Fn scaled
  - Form Drag — constant

$$C_T(Rn, Fn) = C_F(Rn) + C_{WM}(Fn) + C_{FORM}$$

Hughes

- Modifies Froude's hypothesis
- Coefficients
  - Frictional Rn scaled
  - Wave Making Fn scaled
  - Form Drag Rn scaled

$$C_T(Rn, Fn) = C_F(Rn) + C_{WM}(Fn) + C_{FORM}(Rn)$$

Hughes

- Form drag coefficient is proportional to frictional coefficient by some constant

$$C_{FORM}(Rn) = \quad C_{FO}(Rn)$$

$$C_T(Rn,Fn) = r\ C_{FO}(Rn) + C_{WM}(Fn)$$

Hughes Form Factor r

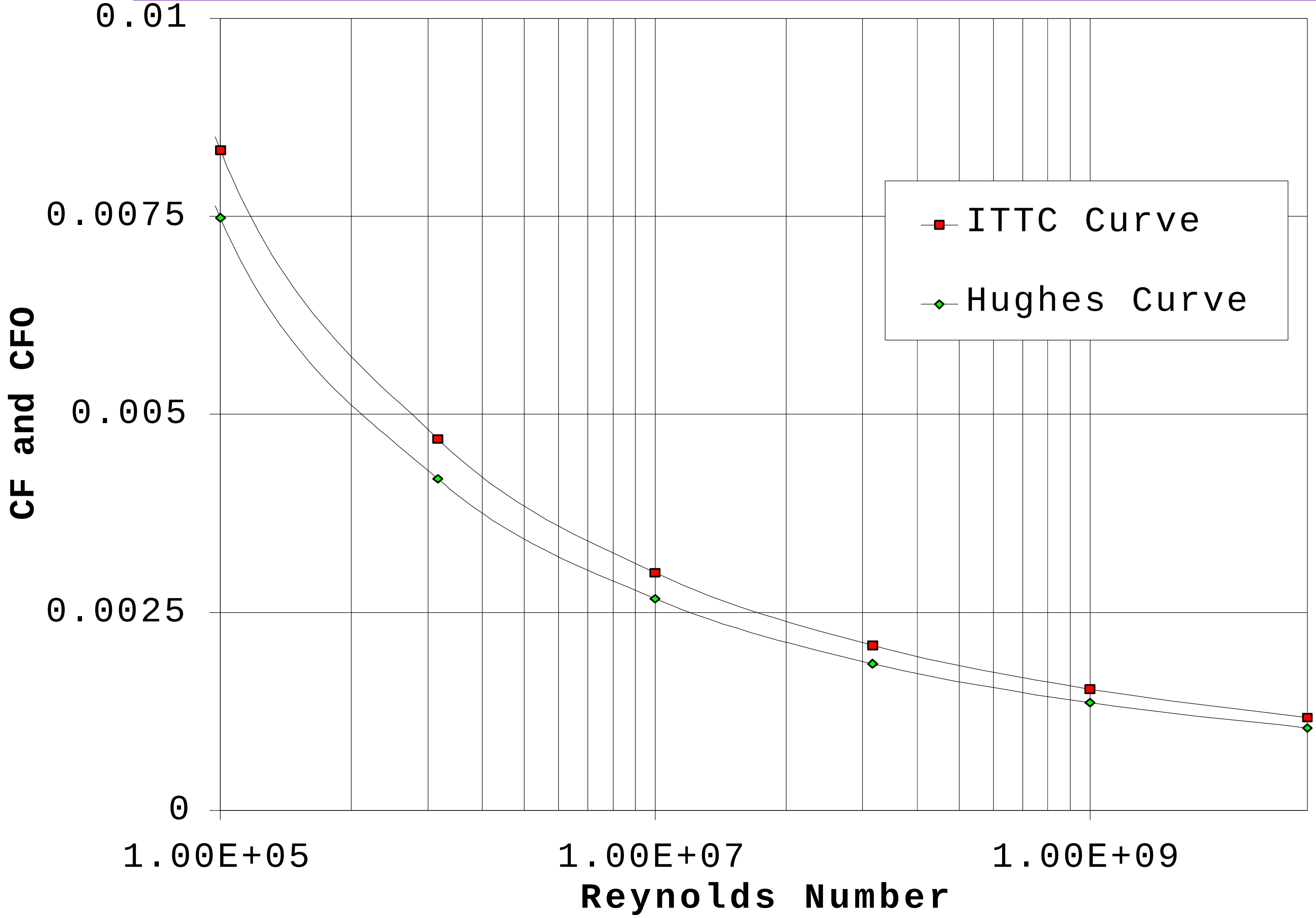
- found by assuming the wave making is negligible at low Froude Numbers (low speeds)

$$C_T(Rn,Fn) = C_{FO}(Rn) + C_{FORM}(Rn) + \underbrace{C_{WM}(Fn)}_{0}$$

$$C_T(Rn,Fn) = (1+ \quad)C_{FO}(Rn)$$

$$C_T(Rn,Fn) = r\ C_{FO}(Rn)$$

ITTC and Hughes Frictional Coefficients



Procedural Comparison

- ITTC
  - give more of the total to skin friction, which is Reynolds scaled
  - Wave Making is Froude scaled
  - Form Drag is constant
- Hughes
  - gives less of the total to skin friction, which is Reynolds scaled
  - Wave Making is Froude scaled
  - Form Drag is Reynolds scaled

Scaling Comparison

- Reynolds Scaling
  - model Rn < ship Rn
  - resistance coefficient decreases with increasing Rn
  - the ship coefficient is less than the model coefficient at equivalent speeds
- Froude Scaling
  - model Fn = ship Fn
  - the ship and model resistance coefficients are the same at equivalent speeds

Reynolds vs. Froude Scaling

- One pound of resistance Reynolds scaled $<$ one pound of resistance Froude scaled

Single Length vs. Sectioned Hull

Single Length

- Monohull approach
  - length determined from Lockheed analysis.
  - roughly equal to the waterline length of the SLICE.

Sectioned Hull

- Divide the submerged hull into strut and pod components
- Sum the individual frictional resistances to find an equivalent coefficient, length, and Reynolds Number
  - larger frictional resistance
  - smaller "equivalent" length and Rn

Why Sectioned Hull ?

- Struts and Pods have significantly different lengths
- SWATH research supports this idea
  - better prediction by separately estimating frictional drag for the different components and summing
  - particularly relevant for 2-strut-per-side SWATH's

Further Modifications

Modified Hughes Method

Why Modify ?

- Large form factor (r = 1.95)
- The form drag was almost as much as the frictional resistance
- Geometrically easy to separate the struts and pods (already done for friction)
  - struts are thin
  - pods are full form

Modification Thoughts

- What if we evaluate the struts as wing shapes ?
- Lots of data on wing shape drag
- Pick a similar shape
- Quantify the strut form drag

Wing Shape: NACA 0012-64

- For the shape, got a wing drag coefficient
- Previously calculated the strut frictional resistance coefficient
- Strut wave making drag $\Rightarrow$ 0

$$C_{T_{Strut}}(Rn, Fn) = C_{FO_{Strut}}(Rn) + C_{WM_{Strut}}(Fn) + C_{FORM_{Strut}}$$

Strut Form Drag

- Set strut form coefficient as constant and scale by Froude's hypothesis

Pod Form Drag

$$R_{FORM_{Pod}} = R_{FORM} - R_{FORM_{Strut}}$$

- Determine pod form drag
- Rn scale the pod portion by the Hughes technique
- The full form shape of the pods suggests Rn dependency

Modified Hughes Resistances

- Frictional
  - Rn scaled (same as Hughes)
- Wave Making
  - Fn scaled (same as Hughes)
- Form Drag
  - divided into strut and pod components
  - PODS: Rn scaled (same as Hughes)
  - STRUTS: Constant coefficient

Correlation Allowance

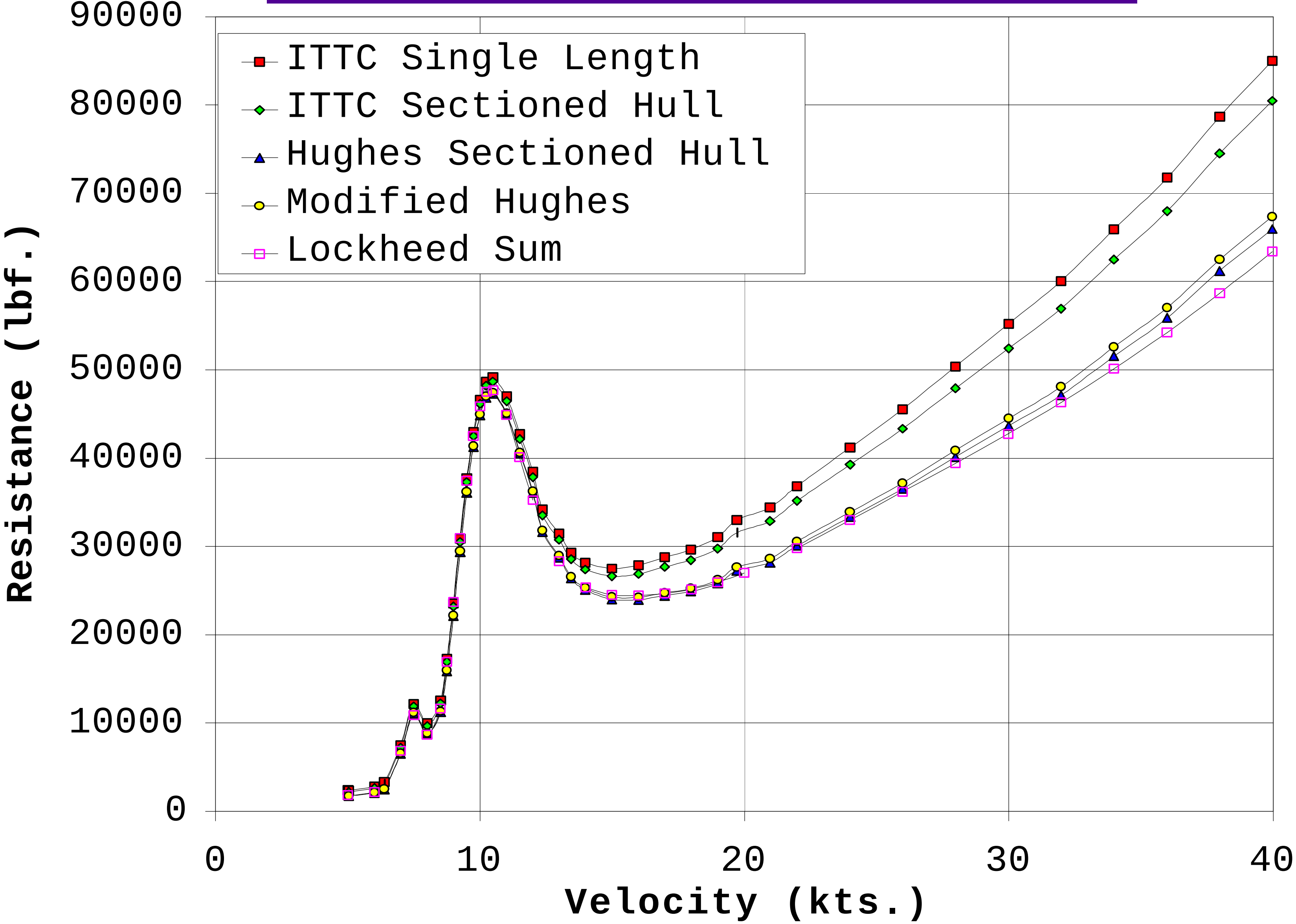
- Added to the ship total to account for underestimation by scaling techniques
- used CA = 0.0005
- For SWATH hulls:
  - CA = 0.0005
- Lockheed:
  - CA = 0.0005

Resistance Calculation

$$R = C\left(\frac{1}{2}\quad S\,V^2\right)$$

- R = Resistance
- C = Resistance Coefficient
- ρ = density of the fluid
- S = wetted surface area
- V = hull velocity

Ship Total Resistance



SHP @ 30 knots

- Lockheed parameters
  - PC = 0.73
  - Lycoming TF 40
    - for continuous operation, can provide 6850 hp

SHP Predictions

- ITTC Single Length
  - will not achieve 30 kts.
- All other scaling procedures
  - sustained 30 kts. is achievable
- for the given propulsive coefficient, believe the SLICE will achieve 30+ knots

Conclusions

- Scaling technique
  - ITTC overestimates
  - Hughes underestimates
- Best analyzed as a sectioned hull vice single length
- Further modifications to monohull scaling techniques should include strut and pod form drag investigations

Recommendations

- CFD analysis of the struts and pods to validate the division of the form drag
  - validate constant scaling for the strut form drag
  - validate Rn scaling for the pod form drag
- Include canards and stabilizers in the resistance calculations

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